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## MURI 2001 Review

# Experimental Study of EMP Upset Mechanisms in Analog and Digital Circuits

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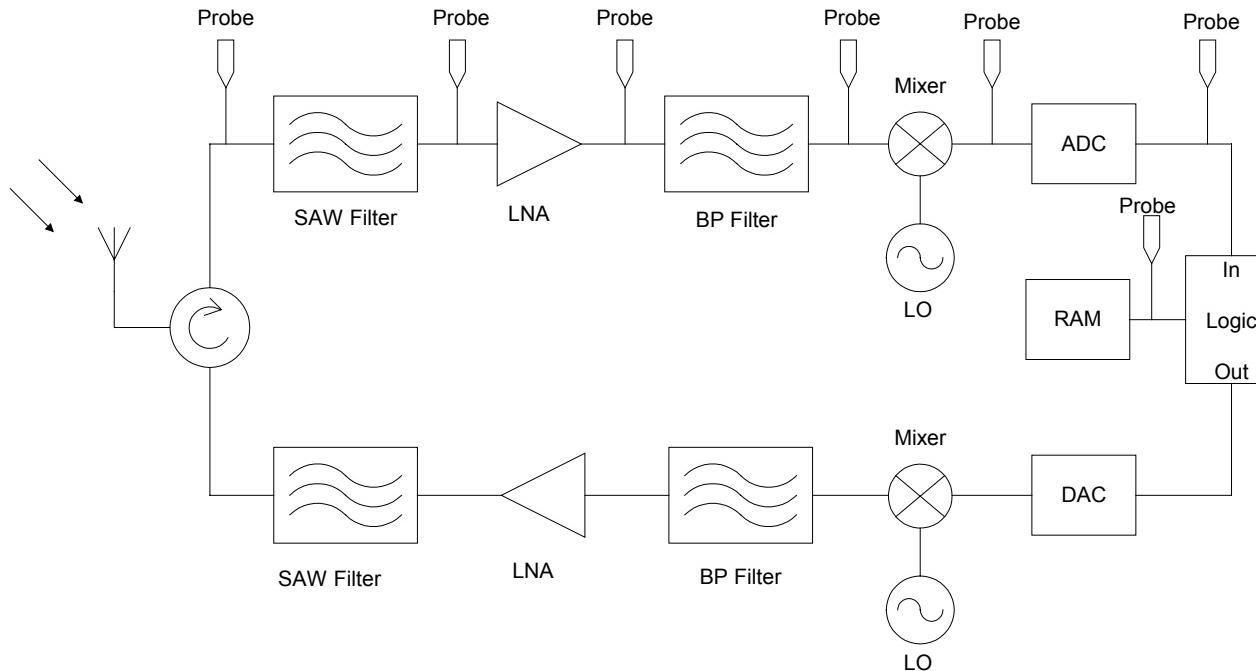
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# Outline and Motivation

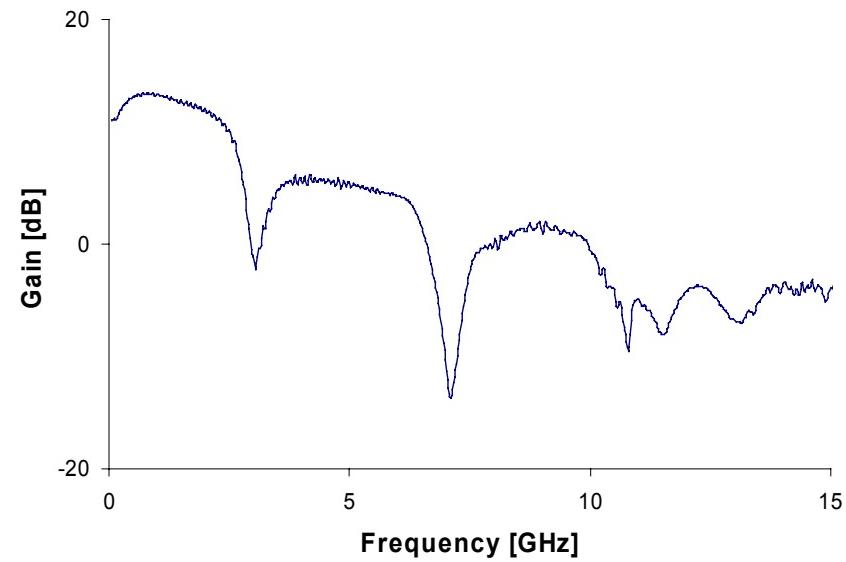
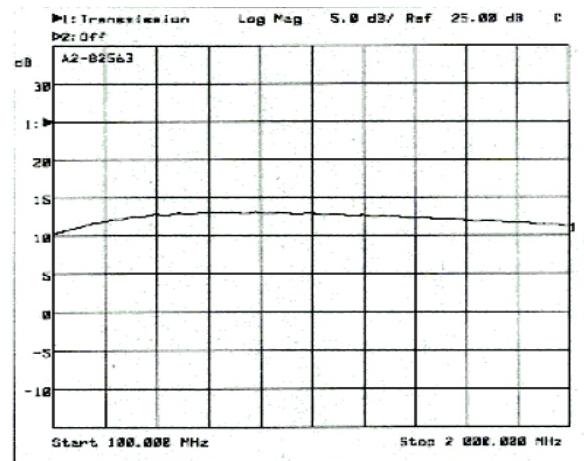
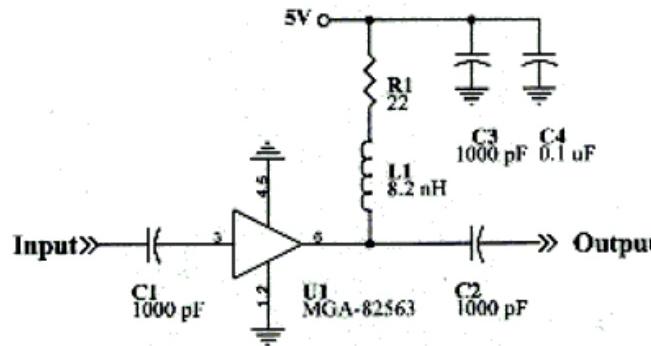
- *Out-of-band frequency response in communications circuits*
  - *Effect of parasitic elements on network performance*
  - *Degradation in filter rejection ratios*
  - *EMP propagation on signal path*
  - *Need for wideband circuit characterization and verification throughout the communications network (RF and IF path, mixer, A/D, power vias, etc.)*
- *Experimental study of device upset using direct RF injection*
  - *Identify RF characteristics that produce bit errors, latch-up*
  - *What are the EMP effects at the device level?*
  - *Modulation and nonlinear circuit response*
- *Directions to pursue*
  - *Experiment*
  - *Modeling*

## Schematic of a “loop-back” test circuit for investigating RF effects in digital communications systems and components

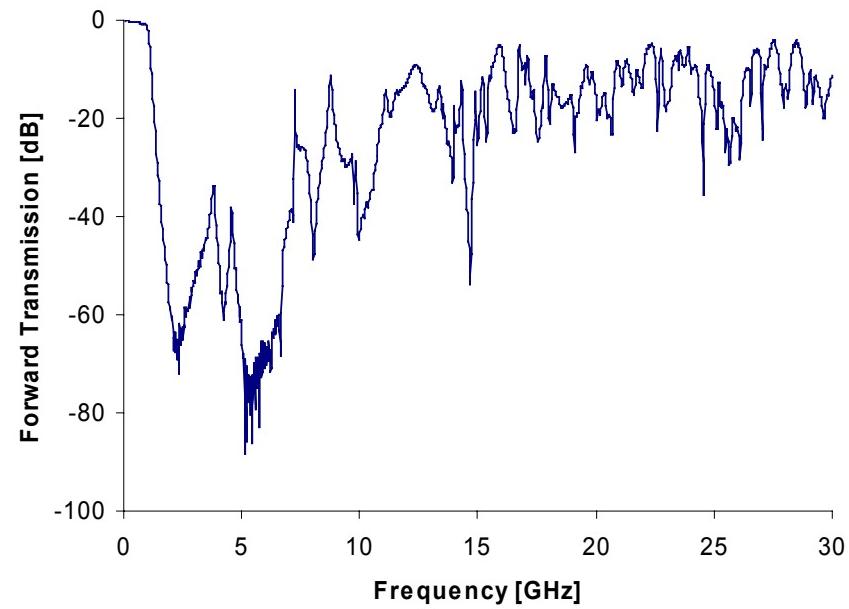
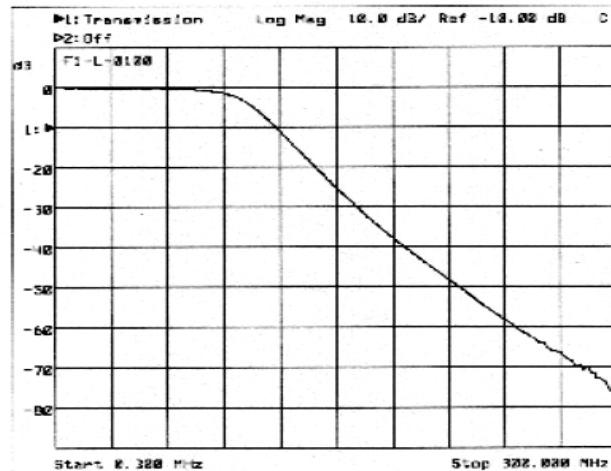
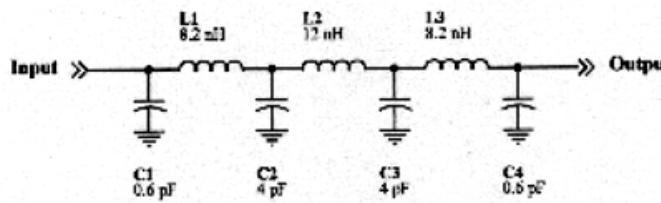


Find possible RF entry points, pathways and circuit effects  
that may upset the system or corrupt data.

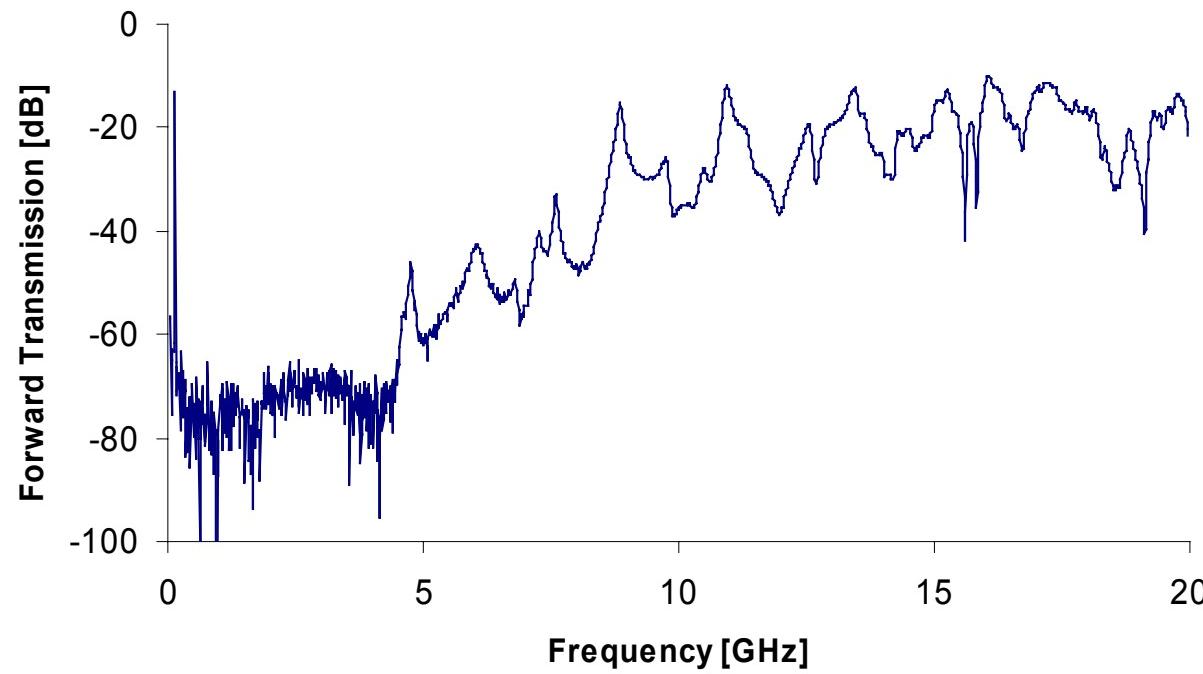
## Example: 2 GHz RF LNA



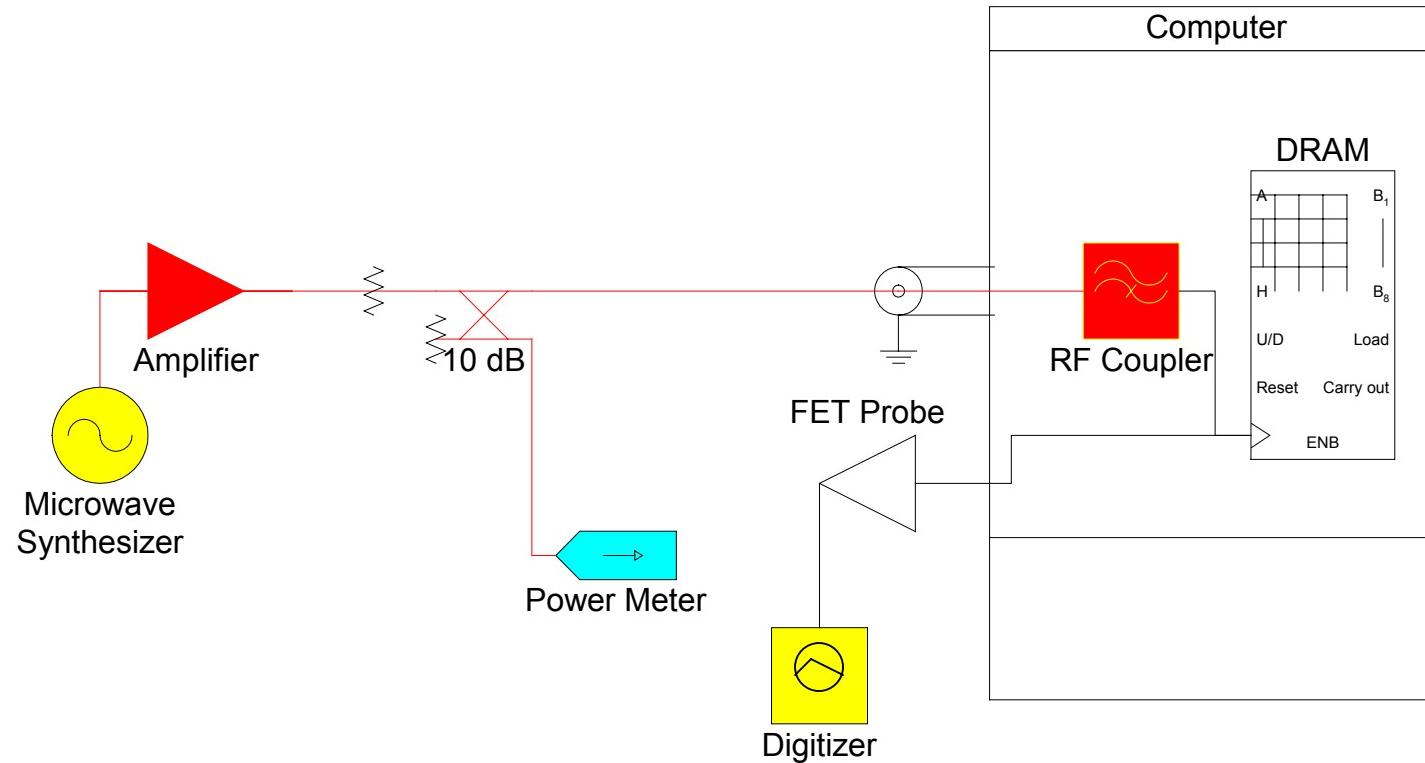
## Example: 1 GHz low pass filter



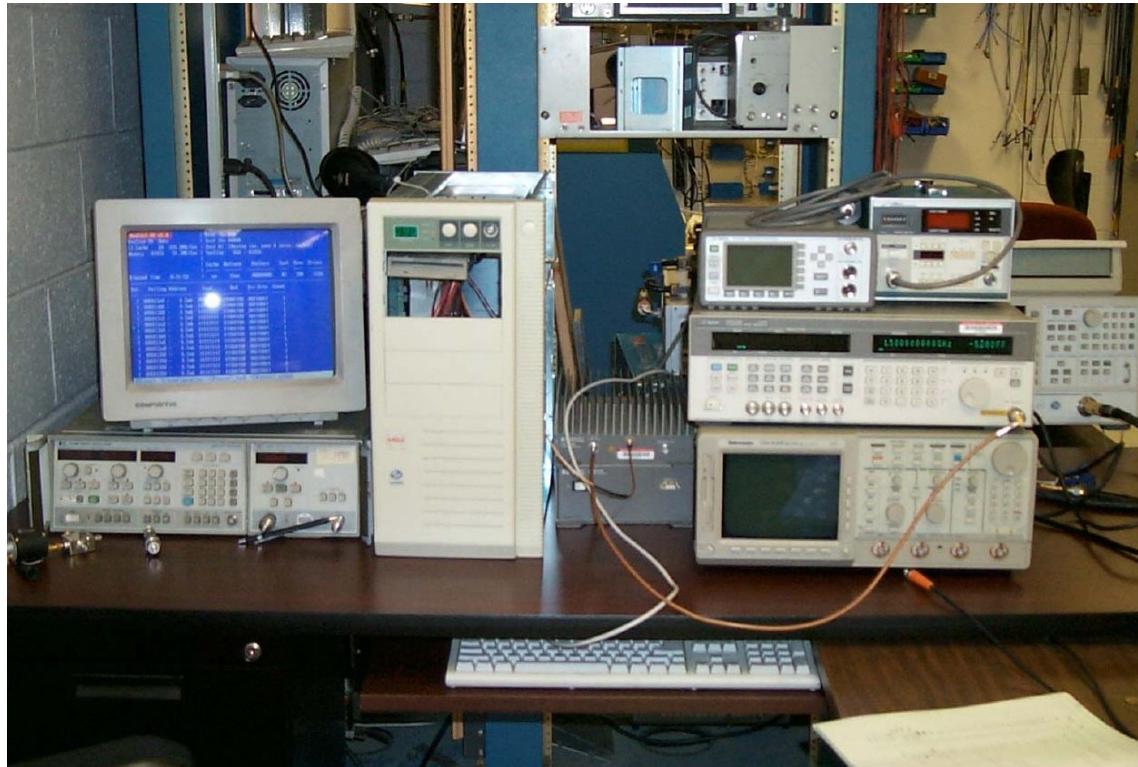
## 140 MHz IF surface acoustic wave (SAW) filter



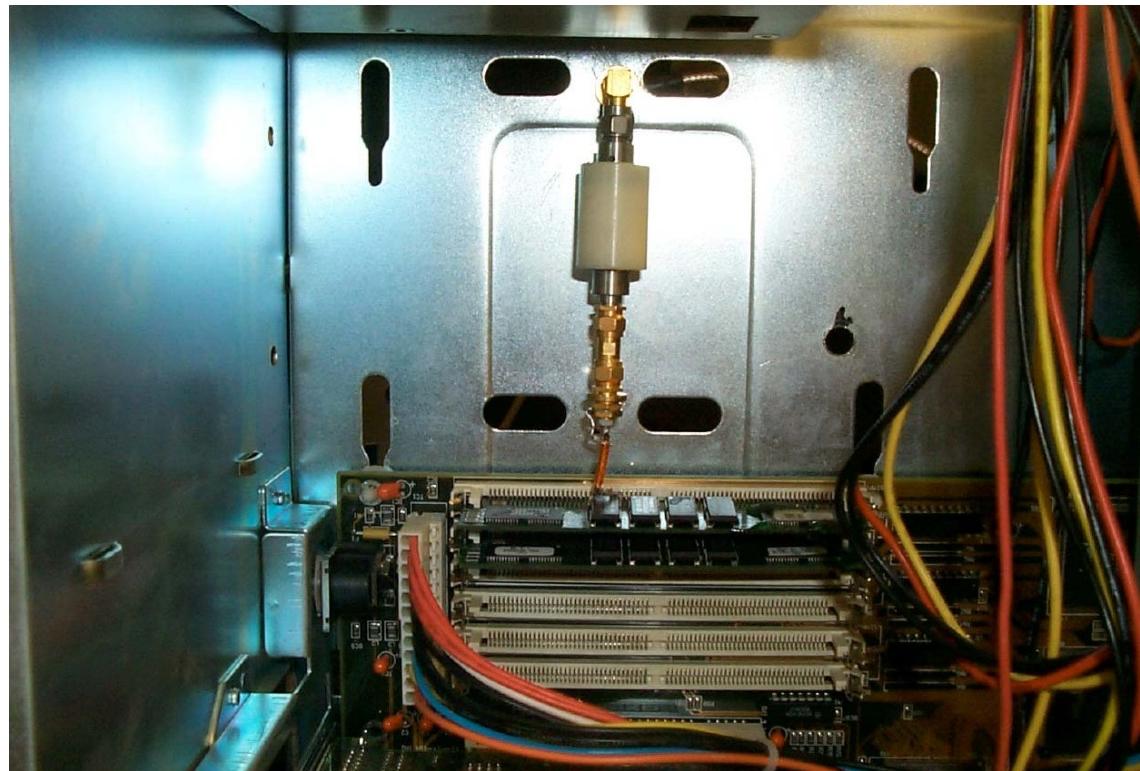
## Schematic of direct injection experiment



## Direct injection test facility



View of injection coupler and memory  
modules inside computer



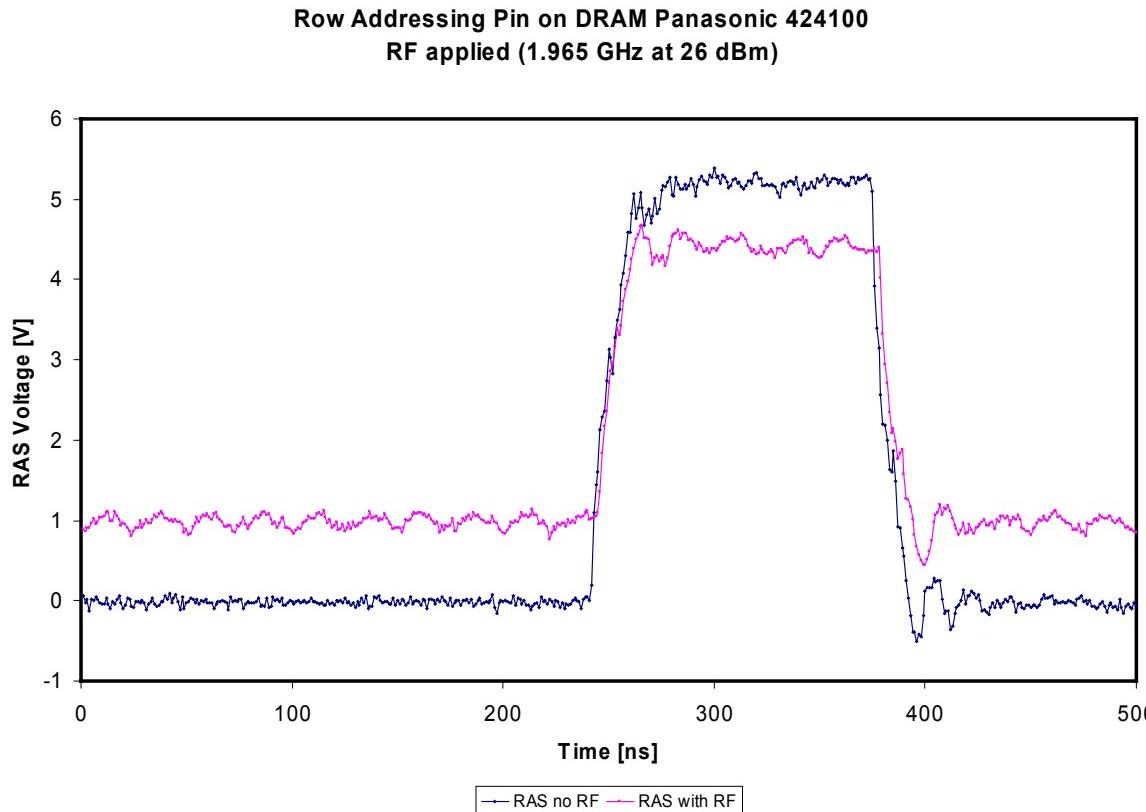
## Memory checking code displaying bit errors

```
mtest-86 v2.4          : Pass10000000000000000000000000000000
ntium 90 .0mhz          : Test10000000000000000000000000000000
Cache 8k 299.9MB/Sec   : Test #1 [Moving inv. ones & zeros, cached]
emory 8192k 19.1MB/Sec : Testing: 0 - 640k Relocated

                                         Cache  Refresh    Pattern   Test  Pass  Errors
Elapsed Time 0:05:09           on      15ms     ffffffff  #1    18    254

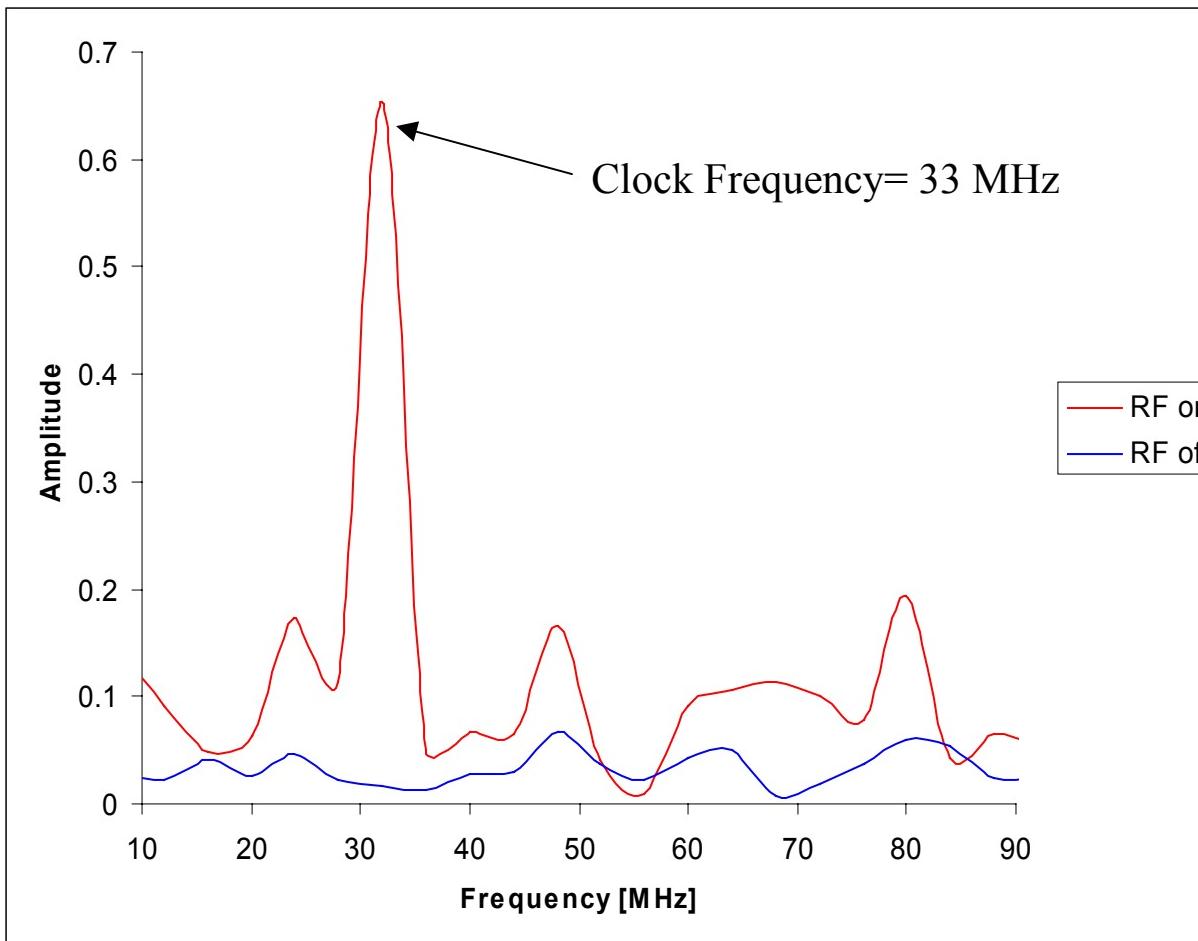
Test  Failing Address      Good     Bad    Err-Bits  Count
-----  -----
1 00077860 - 0.4mb ffffffff ff00ff00 00ff00ff 1
1 00077858 - 0.4mb ffffffff ff00ff00 00ff00ff 1
1 00077850 - 0.4mb ffffffff ff00ff00 00ff00ff 1
1 00077848 - 0.4mb ffffffff ff00ff00 00ff00ff 1
1 00077840 - 0.4mb ffffffff ff00ff00 00ff00ff 1
1 00077838 - 0.4mb ffffffff ff00ff00 00ff00ff 1
1 00077830 - 0.4mb ffffffff ff00ff00 00ff00ff 1
1 00077828 - 0.4mb ffffffff ff00ff00 00ff00ff 1
1 00077820 - 0.4mb ffffffff ff00ff00 00ff00ff 1
1 00077818 - 0.4mb ffffffff ff00ff00 00ff00ff 1
1 00077810 - 0.4mb ffffffff ff00ff00 00ff00ff 1
1 00077808 - 0.4mb ffffffff ff00ff00 00ff00ff 1
1 00077800 - 0.4mb ffffffff ff00ff00 00ff00ff 1
Exit (c)onfiguration (CP)arallel lock (CR)scroll unlock
```

## RAS logic waveform with and without RF injection



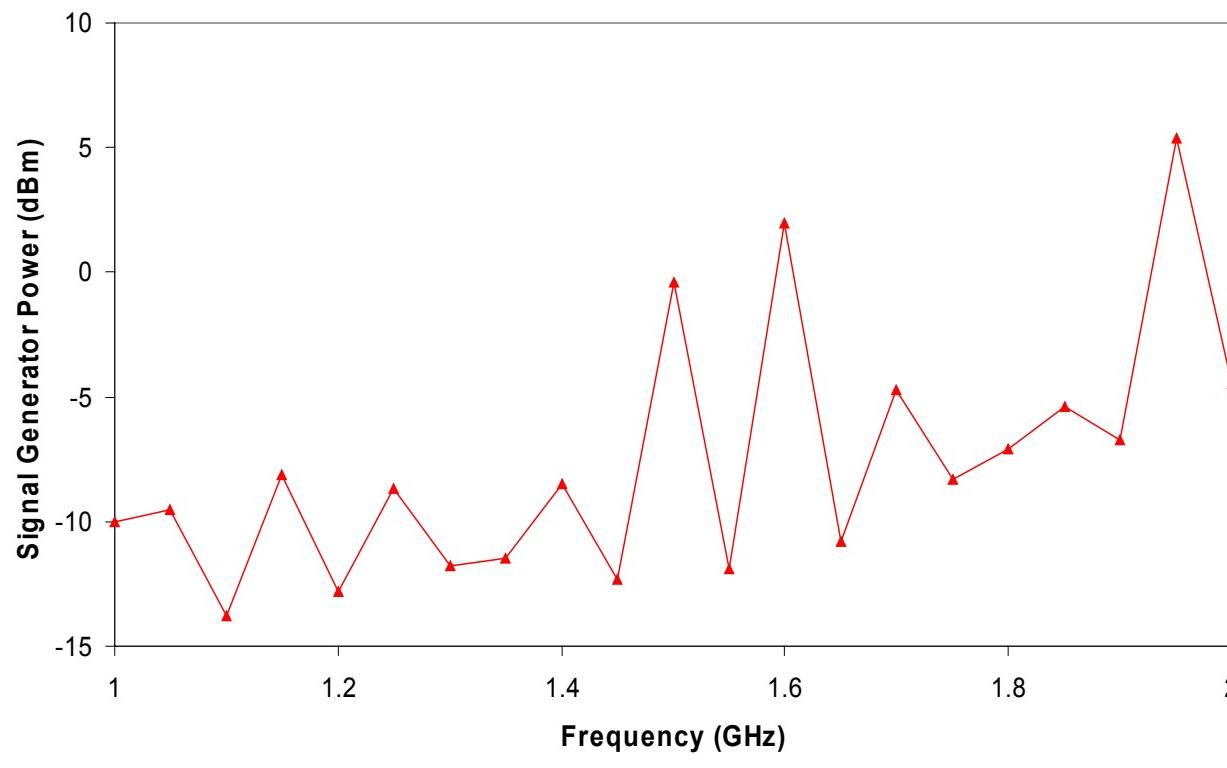
- Device no longer latches to Vdd and Vss
- RF changes operating bias point
- Susceptibility may involve synergistic effects where RF increases likelihood of interference from internal signals.

## Frequency spectrum of RAS waveform



## Results with CW injection

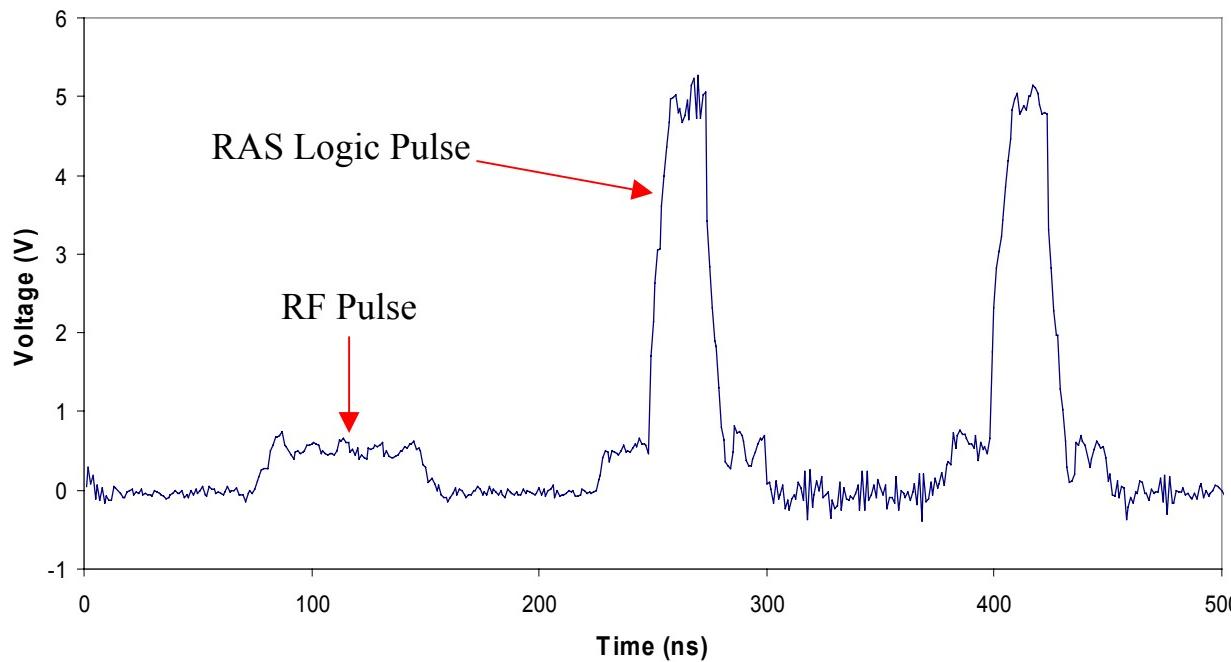
Threshold Power to cause Bit Error at RAS pin  
Signal Generator Power



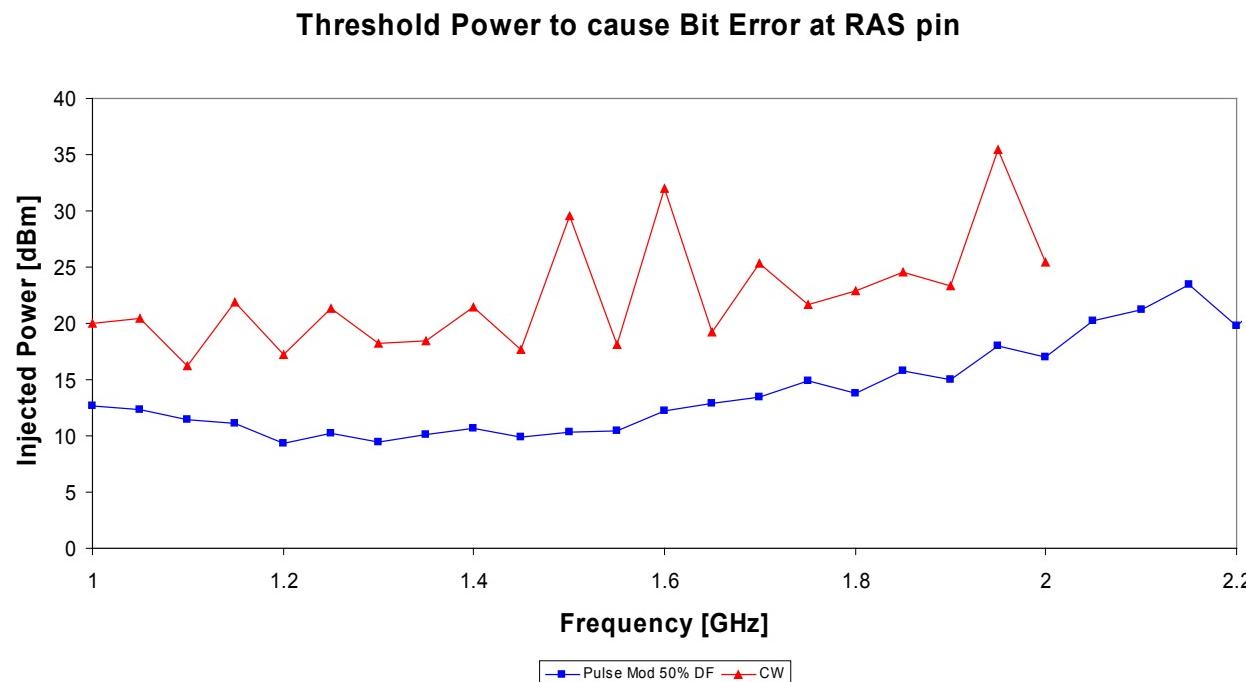
—▲— CW

## RAS Voltage vs. time with Pulsed RF Injection ( $f \sim 2$ GHz)

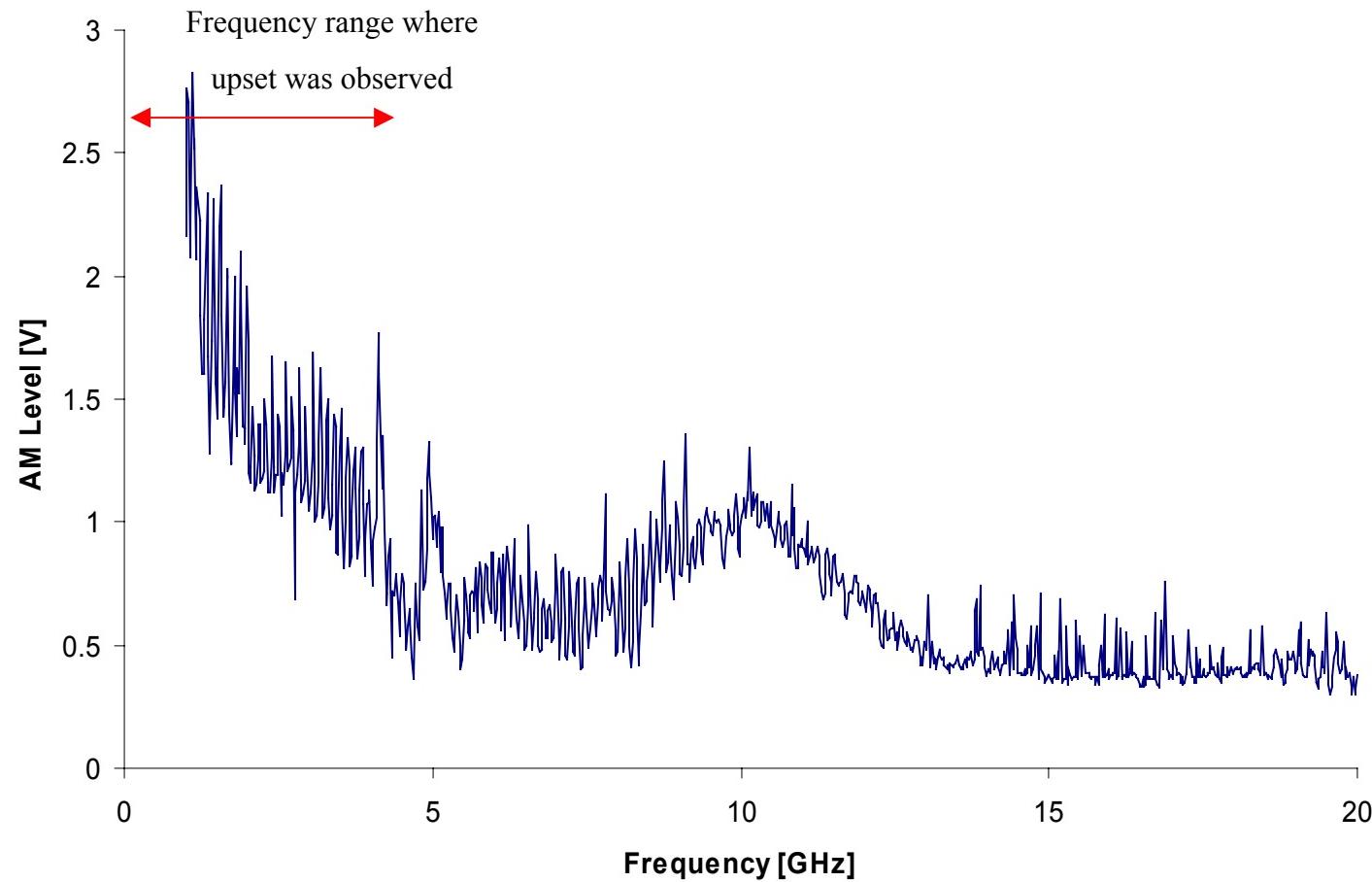
RAS Pin with injected RF before interrupt  
1.965 GHz (PW=150 ns, PRI=300 ns, Pin=29.4 dBm)



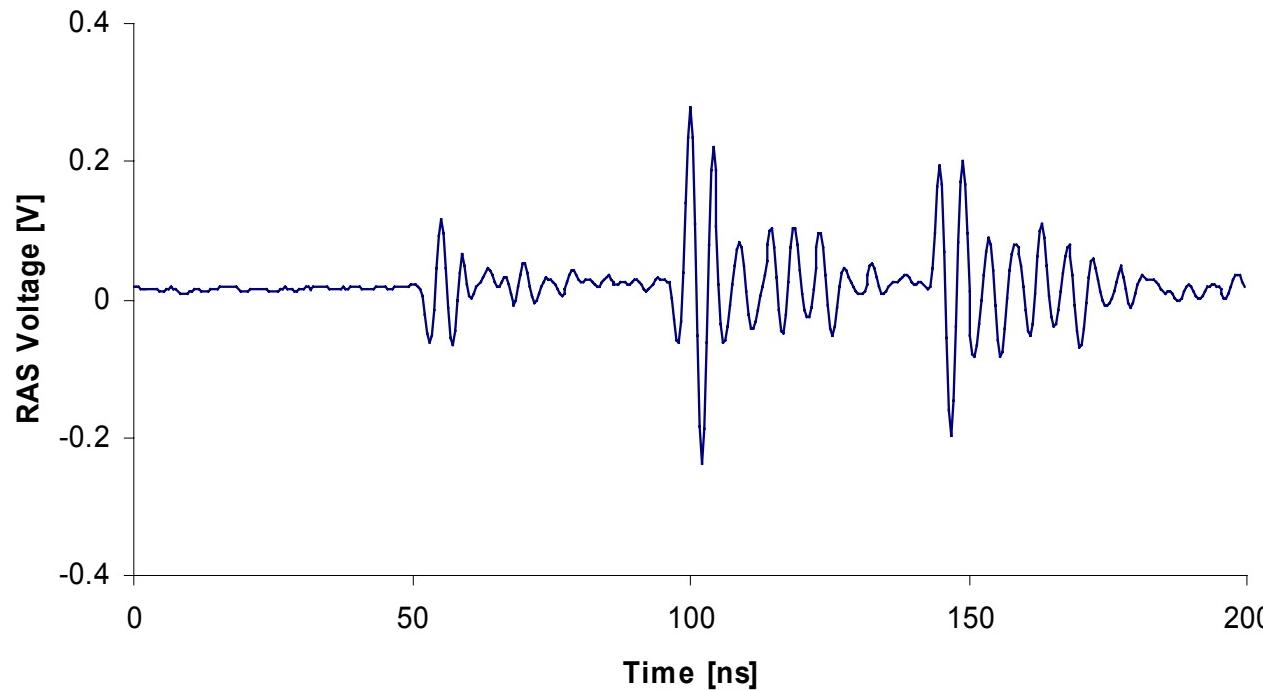
## Comparison of results with CW and pulsed injection



## Amplitude of demodulated RF signal on RAS vs. frequency



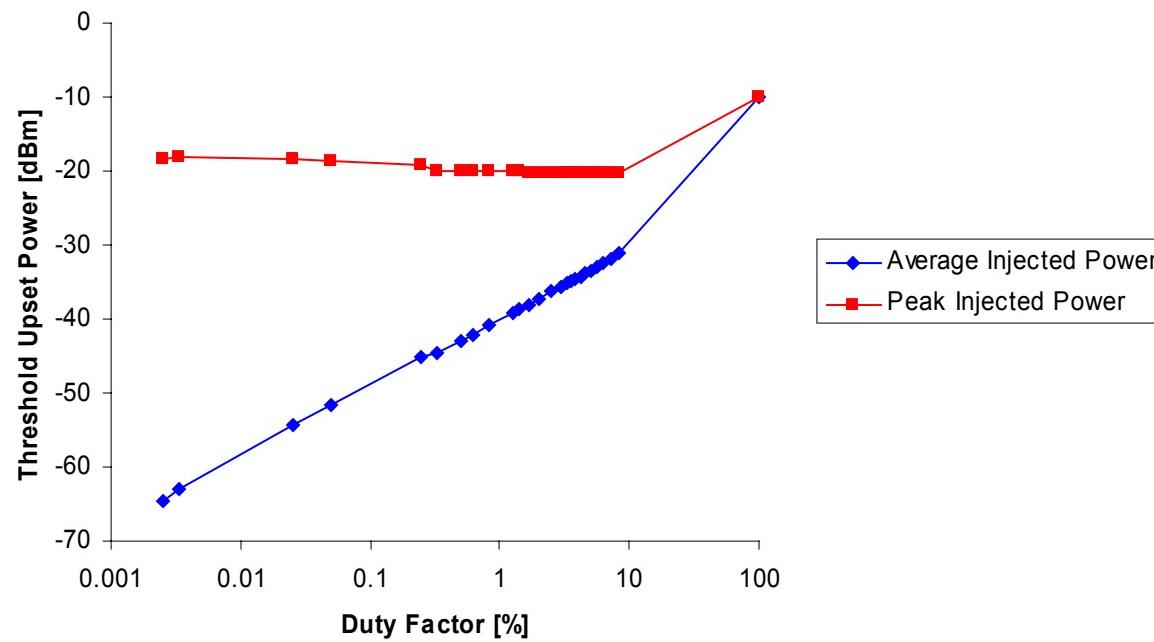
# Transients induced on RAS by RF pulses at frequencies up to 20 GHz



## What mechanisms may be responsible for the observed effects?

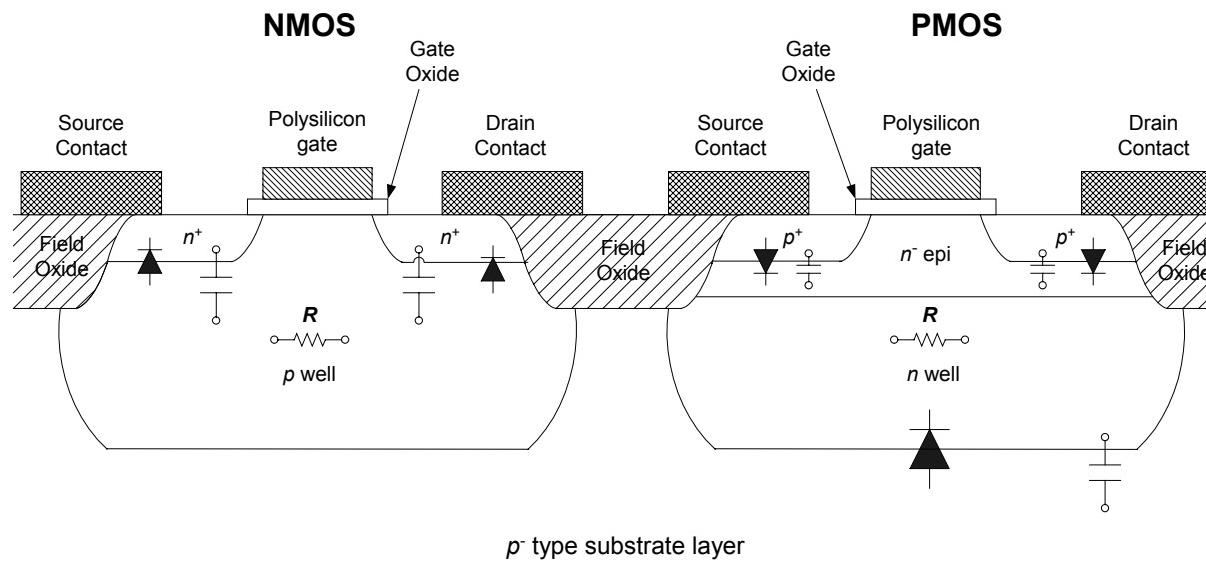
- Thermal: localized RF energy deposition and rapid heating of active MOS regions
- Hot-carriers
- Nonlinear circuit elements
  - MOS diodes acting as RF detectors
  - Demodulation of RF by parametric capacitances

## Upset threshold power vs. duty factor

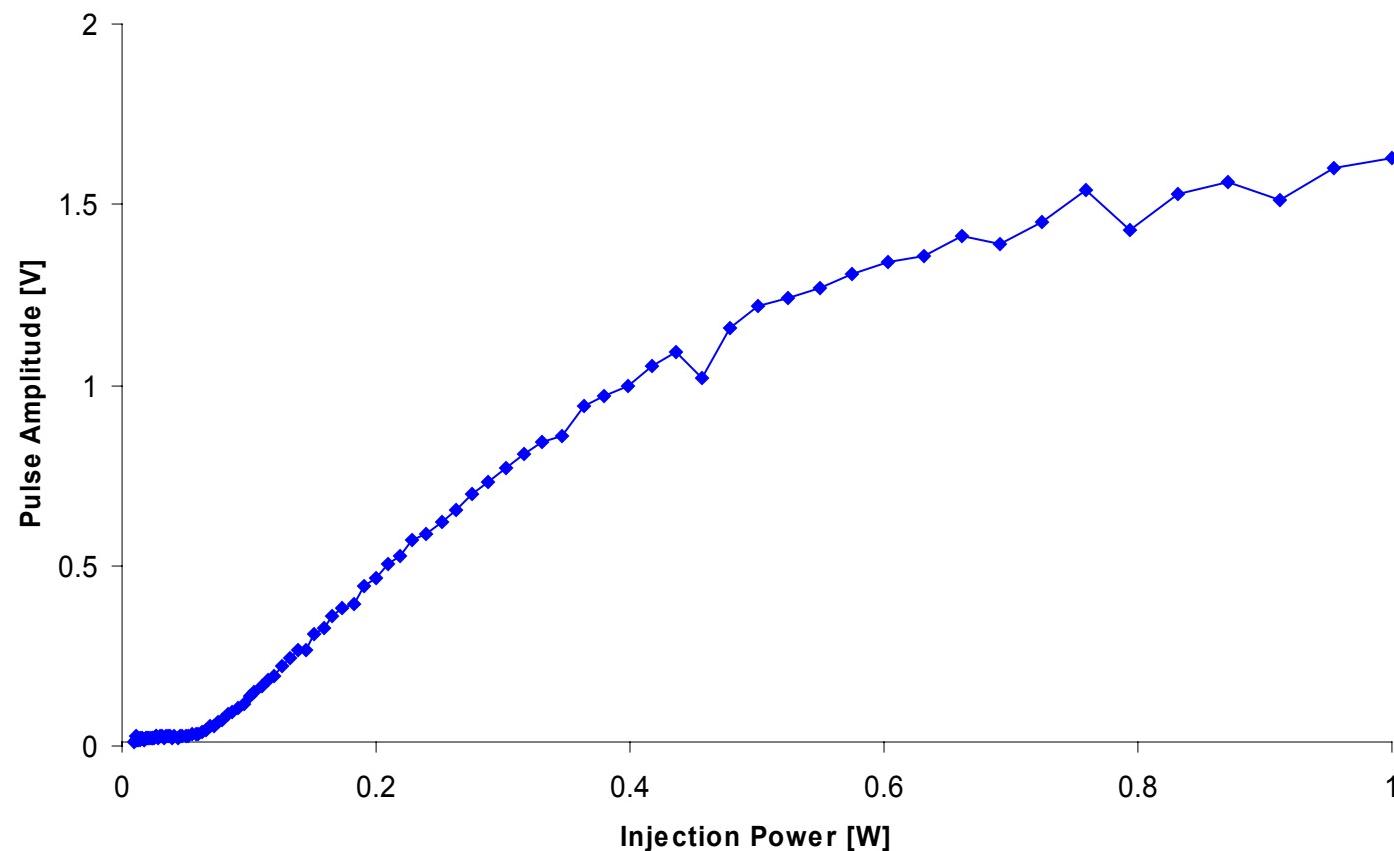


Not a thermal effect

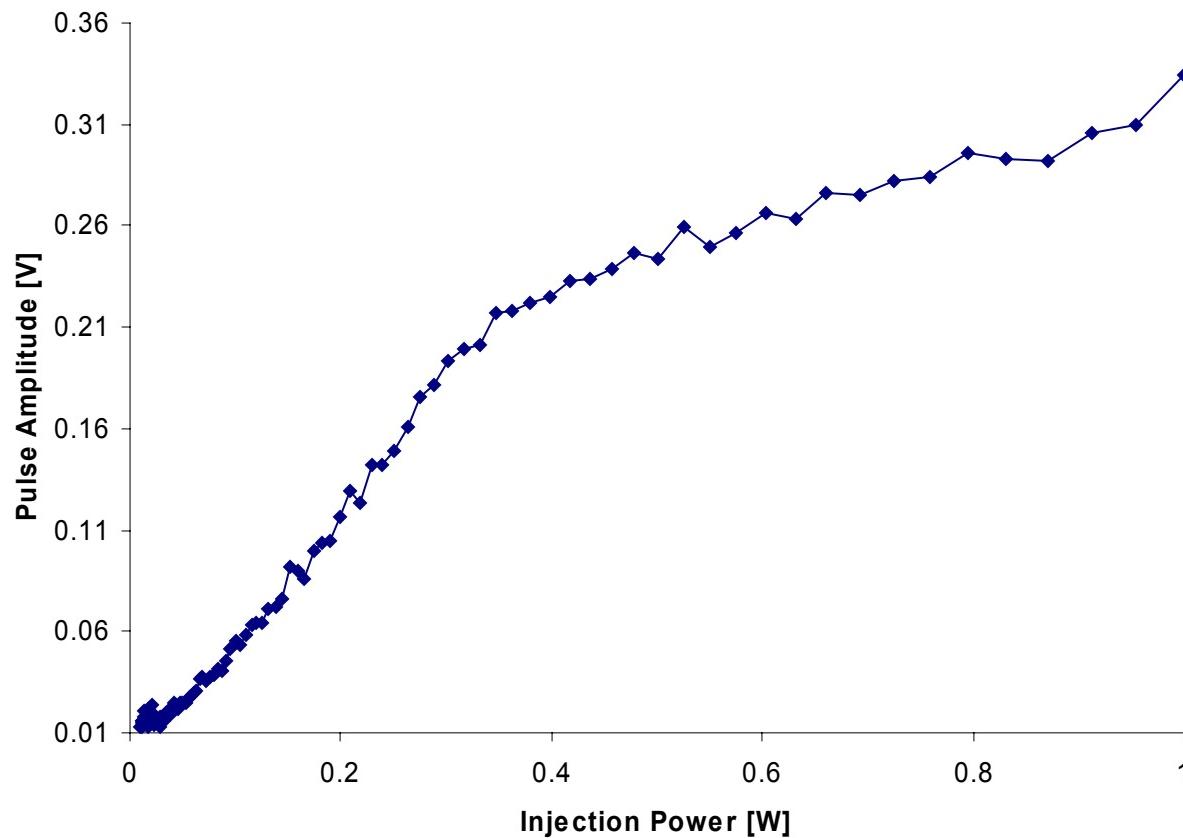
# Physical Cross-section of CMOS showing equivalent circuit elements with nonlinear electrical characteristics



## Drive characteristic of demodulated 4.12 GHz pulse



## Drive characteristic of 6.0 GHz transient pulse



## Conclusions

- High frequency response of communications circuits must be considered when analyzing susceptibility to determine probable entry and propagation paths for EMP.
- The RF shifts the operating bias with respect to Vdd and Vss into a nonlinear amplification regime, which could lead to instability, oscillation and chaotic behavior.
- RF pulses are demodulated by nonlinear MOS elements. The envelop voltage constitutes the interrupting signal.
- EMP rise time is a key parameter for inducing interrupt signals over wide bandwidths.

## Future Work

- The experimental results give basis for modeling high frequency effects in devices
- Continue to characterize device-level upset mechanisms and seek to develop generalized formalisms
- Study the effects of complex modulation
- Look at smaller, faster structures (CPU, RDRAM, DDR, etc.) and investigate how scaling laws may be applied
- Investigated RF effects in mixed signal systems (A/D, demodulators, etc.)